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Macro BIM adoption: Comparative market analysis

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ABSTRACT

The adoption of Building Information Modelling (BIM) across markets is a pertinent topic for academic discourse and industry attention. This is evidenced by the unrelenting release of national BIM initiatives; new BIM protocols; and candidate international standards. This paper is the second part of an ongoing Macro BIM Adoption study: the first paper "Macro BIM Adoption: Conceptual Structures" (Succar and Kassem, 2015) introduced five conceptual models for assessing macro BIM adoption across markets and informing the development of BIM adoption policies. This second paper clarifies how these models are validated through capturing the input of 99 experts from 21 countries using a survey tool; highlights the commonalities and differences between sample countries with respect to BIM adoption; and introduces sample tools and templates for either developing or calibrating BIM adoption policies.

Survey data collected indicate that all five conceptual models demonstrate high levels of 'clarity', 'accuracy' and 'usefulness', the three metrics measured. They also indicate (1) varying rates of *BIM diffusion* across countries with *BIM capability* near the lower-end of the spectrum; (2) varying levels of *BIM maturity* with - the mean of - most macro BIM components falling below the medium level; (3) varying *diffusion dynamics* across countries with the prevalence of the middle-out diffusion dynamic; (4) varying *policy actions* across countries with a predominance of the passive policy approach; and (5) varying distribution of *diffusion responsibilities* among player groups with no detectable dominant pattern across countries.

The two papers provide an opportunity to improve our understanding of BIM adoption dynamics across countries. Future research can build upon the models and tools introduced to enable (a) an expansion of benchmarking data through surveying additional countries; (b) identifying BIM adoption changes in surveyed countries over time; (c) correlating changes in adoption rates/patterns with policy interventions; (d) identifying BIM policy variations within the same country; (e) establishing statistical correlations between the conceptual models; and (f) developing new tools to facilitate BIM policy development and encouraging BIM adoption.

1. Introduction

Building Information Modelling (BIM) causes concurrent evolutionary and revolutionary changes across several scales within the organisational hierarchy ranging from individuals and groups; through organisations and project teams; to industries and whole markets [41,42]. Investigating the role BIM adoption plays at the largest organisational scales (i.e. countries or markets) has recently started to attract the attention of researchers. As a delimited area of research, investigating the implementation and diffusion of BIM within a country or across countries is referred to here as 'macro BIM adoption'; with 'macro' denoting a large collections of organisational adopters operating within a defined national border; 'BIM' encapsulating a set of interacting technologies, processes and policies; and 'adoption' representing the combined connotations of readiness, implementation and diffusion.

While many countries are investigating, developing or delivering a national BIM policy to facilitate BIM adoption across their respective markets, there is still a dearth of studies and methodologies for assessing and comparing existing policies, or for assisting in the formulation of new ones. With the absence of researcher-led, evidence-based approaches to macro BIM adoption, commercially-driven surveys have flourished [15]. These include a multiplicity of industry reports with data covering BIM diffusion in the UK, France and Germany [25]; Autodesk software uptake in Europe [1]; BIM diffusion in the U.S. and Canada [26]; BIM diffusion in the UK [29–31]; The Business Value of BIM in Australia and New Zealand [27]; and many others. In addition to these industry reports, many researchers have also

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conducted market-wide surveys but with heightened rigour and sturdier data collection methodologies. These studies covered a large number of countries, including: Australia [12], China [5], Finland [21], Iceland [18], India [24], South Africa [9], Sweden [37], Taiwan [28], United Kingdom [17], United States [11,23], and multi-markets [38,35,45,48].

While both industry surveys and academic studies provide valuable insights into BIM diffusion rates across markets, they are not intended to evaluate or compare current BIM policies or to assist stakeholders to develop new BIM adoption policies. To address this gap, a research effort has been conducted and consecutively published. The first paper ([43] – referred to as Paper A henceforth) introduced five conceptual models for assessing macro BIM adoption across whole markets and aiding the development of new policies. This second paper (referred to as Paper B henceforth) will build upon the conceptual foundations by using the five models to analyse BIM adoption across 21 countries with the participation of 99 experts. It will then demonstrate how these conceptual models can be combined into BIM policy roadmaps and BIM policy plans.

2. Key terms and concepts

This research investigates aspects that are pertinent to the adoption of BIM at country-level or market-wide scale. As many of the terms used may have competing definitions, Table 1 below provides a succinct description for the main terms used throughout this study:

3. Methodology

The first part of this research (Paper A) introduced five macro BIM adoption models and described the process underpinning their conceptual development. The five macro adoption models (Table 1) were developed for the purpose of (i) analysing existing national BIM policies, and (ii) aiding the development of new national BIM policies. Table 2 below reintroduces the models and briefly explains their specific uses. These conceptual constructs are inventions of the human mind allowing the organisation, and promoting the understanding, of observations [2]. To validate the conceptual constructs against 'real world' situations [2], a research process needs to be undertaken. This process, according to Buckley et al. [4], must (a) be an orderly investigation into a well-defined problem; (b) apply appropriate scientific methods to gather representative evidence; (c) be based on logical unbiased reasoning; and (d) yield cumulative results which can be replicated under similar conditions in the future.

This paper aims to validate the five conceptual constructs by analysing the input of 99 experts from 21 countries (Table 3) who participated in the validation effort throughout 2015 and early 2016.

Three criteria were adopted for the selection of countries: 1. the country has active on-going discussions about national and international BIM policies, 2. the country has identifiable professionals who are well-informed about national and international BIM policies, and 3. the selected countries are patchily distributed across all continents. Some countries satisfied the three criteria but were excluded from the final sample (21 countries) due to the insufficient number of respondents (i.e. less than three) and the unwillingness of experts to participate in the survey. These countries included Belgium, France, Germany, Latvia, Norway, Saudi Arabia, South Africa, South Korea and Taiwan.

Starting with an initial set of BIM experts from the researchers' own network, a combination of the *purposeful sampling and* the *snowball* method were adopted.

The *purposeful sampling* method [6] allow the researchers to select only the participants who possess the traits and qualities necessary to provide meaningful input and reliable assessment of macro BIM adoption within the select country thus, fulfilling the research's stated aims [19]. In purposeful sampling the "general rule about the sample size is that quality is more important than quantity" ([19], p. 467). This method allowed the researchers to select the initial group of participants as (1) belonging to a wide range of organisations - public authorities, educational institutions, construction organisations, software developers, value-adding resellers, industry associations, communities of practice, and technology advocates; and (2) actively and publicly involved in high-level BIM discussions within their respective countries.

To identify pertinent participants, the snowball method [32] helped in the recruitment of a seed group of participants through direct communication. Participants were then asked – upon completion of the survey - to assist in recruiting a second group of similarly-qualified participants, who then assisted in recruiting a third group [13]. According to Hippel et al. [14], this recruitment approach is suitable for identifying well-informed participants with high levels of domain expertise.

It is prudent to clarify the generalisability of the results with regards to each of the two study aims: (A) the validation of the conceptual models and (B) the assessment and comparison of the BIM policies of the sample countries. With regards to the first aim, the results from the whole sample (the *absolute* sample size of 99 participants) can be used to provide generalizable and valid results. For the second aim, each country's participants (*relative* sample size varying between a minimum of two and a maximum of 16 participants) input are considered in the results, which are specific to the country. The relative samples of each country – as presented in this paper - are considered small for quantitative studies. However, given the significant scale of the study (21 countries) and its cross-sectional nature – assessment and comparison of surveyed aspects at a single *point in time*, a balanced approach between the precision of the results and the study time has to be made. To further support and expand the data collected to date, additional responses will be continuously collected - from the 21 countries covered in this study and additional countries over time – from new participants through a dedicated online tool to be launched in the near future.[1]

The approach used to collect data from participants is required to communicate both the conceptual models and the questions around each of the models in a consistent way to all participants. This is challenged by the geographical dispersion of participants and the risk misinterpretation due to language differences. To reduce this communication risk, several tools were adopted. First, a short video explanation of each macro adoption model was inserted preceding the question set specific to that model. Second, for participants willing to expand upon the simple video explanation, links to more detailed information – hosted on a dedicated weblog (http://www.bimframework.info/) – were provided. Third, data collection forms were first piloted with three experts to ensure the questions posed were understandable, and the survey instructions were clear.

To avoid central tendency bias caused by extreme response categories (e.g. strongly agree or strongly disagree) [3], both model-specific metrics, and clarity, accuracy and usefulness metrics were evaluated using a simple five-level index with five generic labels: [a] Low; [b] Medium–low; [c] Medium; [d] Medium–high; and [e] High. Data collection was conducted using an online form subdivided into five sections dedicated to the five macro adoption models. Participants were provided the option to exit at the end of each section.

The number of respondents for each of the model is reported in Table 4 followed by an analysis of data collected for model-validation purposes.

[1] A dedicated online tool for ongoing data collection will be made available as part of the BIMe Initiative, Macro BIM Adoption Project. The data collected through the online too will allow the periodical publication of macro adoption results and the generation of interactive tables and comparative charts. For more information, please visit http://bimexcellence.org/projects/macro-adoption/.

Table 1
Terms and definitions.

Term	Description
Adoption	A single construct combining the concepts of implementation and diffusion [43]. Implementation is considered as a three-phased approach combining an organisation's readiness to adopt; its capability to perform, and its performance maturity [44]
→Point of adoption	This point separates between the capability stages (i.e., pre-BIM, modelling, collaboration, and integration) [44]. It marks the capability jump that occurs during the progression between these capability stages.
→Adoption benchmark	The application of specialised models and their corresponding tools to systematically assess and compare macro BIM adoption across countries
Diffusion	A concept that represents the spread of the system/process within a population of adopters
Implementation	The set of activities undertaken to prepare for, deploy or improve specific deliverables (products) and their related workflows (processes)
→Readiness	The pre-implementation status representing the propensity of an organisation to adopt BIM tools, workflows and protocols. It is expressed as the level of preparation, the potential to participate, or the capacity to innovate
→Capability	The abilities gained during the willful implementation of BIM tools, workflows and protocols. It is achieved through is achieved through well-defined revolutionary stages (object-based modelling, model-based collaboration, and network-based integration) separated by numerous evolutionary steps [39,40]
→Maturity	The gradual and continual improvement in quality, repeatability and predictability within available capabilities
Macro	An Organisational Scale representing a large collections of organisational adopters operating within a defined national border
Policy	A course or principle of actions adopted or proposed by a policy maker [8]
→BIM policy development	The set of activities undertaken by a policy maker within a defined market to encourage the adoption of BIM tools, workflows and protocols

4. Part I: validation and applications of the models in 21 countries

This section presents the results from subjecting the five Macro-BIM adoption models to validation through international subject matter experts. After reporting on clarity, accuracy and usefulness of each model, the remaining sections describe the results derived from applying the five models in assessing BIM adoption across 21 countries and identifying any communalities, differences and trends.

4.1. Establishing the clarity, accuracy and usefulness of the five models

The participating experts were asked to rate each model for *clarity*, *accuracy* and *usefulness*. Verifying '*clarity*' establishes whether each model was well-understood by the participating expert; verifying '*accuracy*' establishes whether each models was perceived to be representative of the concepts they claim to represent; and verifying '*usefulness*' establishes whether each model is perceived to fulfil their intended purpose.

The results from the rating exercise are collated in Tables 5–7.

The results in Tables 5–7 indicate the highest scores achieved:

- Clarity (Table 5) was rated mostly as Medium-High and High. Combined ratings at the highest two levels ranged between a minimum of 72% for Model B and a maximum of 88% for Models C and E.
- Accuracy (Table 6) was rated mostly as Medium or Medium-High. Combined ratings at the highest two levels ranged between a minimum of 48% for Model A and a maximum of 77% for Model E.
- Usefulness (Table 7) was rated as either High or Medium-High. Combined ratings at these two levels ranged between a minimum of 68% for Model A and a maximum of 80% for Model B.

These scores highlight that – while the models can still be calibrated and improved upon – they have been perceived by research participants to enjoy relatively high levels of clarity, accuracy and usefulness.

4.2. Analysis of results for each model

Each Macro-BIM adoption model is used to assess specific BIM policy aspects (see column 'Intended Use' in Table 2). Research participants, after viewing an optional explanatory video, were asked to rate the BIM adoption in their respective countries using a five-level index: [a] Low (1 point); [b] Medium–low (2 points); [c] Medium (3 points); [d] Medium–high (4 points); and [e] High (5 points). The below sections summarises the findings from applying each model across 21 countries. The overall discussion covering all models is included in the Conclusion section.

Model A: Comparing the BIM Areas of Diffusion across countries.

Model A establishes the extent of BIM Diffusion within markets by overlaying three BIM Fields (technology, process and policy) with BIM Capability Stages (modelling, collaboration and integration) to generate nine Diffusion Areas [43]. The results from the 21 countries are reported in Fig. 1:

The results reveal an uneven distribution of the Diffusion Rates across countries. For example, in the Netherlands, the United Kingdom, China, Finland and South Korea, the diffusion is moderately balanced across all Diffusion Areas. While in Brazil, Italy, Malaysia, Mexico, Russia, Spain, Switzerland, Qatar and the UAE, the diffusion appears unbalanced with some Diffusion Areas missing. A country with either an unbalanced distribution or missing Diffusion Areas would arguably face different adoption challenges compared to a country with existing and well-distributed diffusion across the nine areas.

The Diffusion Areas Model aggregates organisational abilities across three BIM capability stages (modelling, collaboration and integration) and three BIM fields (technology, process and policy). Fig. 2 identifies a common trend across 18 of the 21 countries: a high concentration of low-level capability (modelling) followed by lower collaboration and integration capabilities.

The standard deviations from the application of this model demonstrated elevated confidence levels: 147 (78%) out of the 189 assessed elements (i.e. nine areas of diffusion across 21 countries) have their standard deviations within a unit interval on the applied Likert scale. These results are adequate for this study at its *discovery* stage and will improve as more data is collected in the future. The highest standard deviation (i.e. 1.5) is recorded four times: two occurrences in Canada for 'integration processes' and 'integration policies'; one occurrence in the Netherlands for 'integration processes'; and one occurrence in Mexico for 'modelling processes'.

Model B: comparing the macro maturity components across countries.

Model B includes eight complementary components to establish the BIM maturity of countries – these are: Objectives, stages and milestones; Champions and drivers; Regulatory framework; Noteworthy publications; Learning and education; Measurements and benchmarks; Standardised parts and deliverables; and Technology infrastructure.

The participants were given the description of the metrics used for the 'Discovery' assessment of each component (a description of the discovery metric relevant to each macro component is available on:

Table 2
List of macro BIM adoption models, matrices, charts and intended use [43].

	Model title	Intended use	Matrix or chart
A	Diffusion areas model 	Establish the Extent of BIM Diffusion across markets. The model overlays **BIM Fields** (technology, process, and policy) and **BIM Stages** (modelling, collaboration, and integration) [39,40]	Diffusion Areas *matrix* + Diffusion Areas *sample chart*
B	Macro maturity components model 	Assess the BIM maturity of countries holistically using a comparative matrix or granularly using component-specific metrics. The model includes **8 Macro Components**: Objectives, Stages & Milestones; *Champions & Drivers*; Regulatory Framework; *Noteworthy Publications*; Learning & Education; *Measurements & Benchmarks*; Standardised Parts & Deliverables; and *Technology Infrastructure.*	Macro Maturity *matrix*
C	Macro diffusion dynamics model 	Assess and compare the directional pressures and mechanisms affecting how diffusion unfolds within a population. The model includes **3 Diffusion Dynamics**: Top-Down, Middle-Out and Bottom-Up. **3 Pressure Mechanisms**: Downwards, Upwards and Horizontal; and **3 Pressure Types**: Coercive, Normative, and Mimetic.	Macro Diffusion Dynamics *matrix*
D	Policy actions model 	Identify, assess and compare the actions policy makers take (or can take) to facilitate market-wide adoption. The model includes **3 Policy Approaches**: Passive, Active, and Assertive; and **3 Policy Activities**: Make Aware, Encourage and Observe	Policy Actions *matrix* + Policy Action Patterns *sample chart* **Error! Reference source not found.**
E	Macro diffusion responsibilities model 	Assess and compare the roles played by different stakeholder groups in facilitating diffusion within and across markets. The model uses **BIM Fields** to identify **9 Player Groups**: Policy makers, educational institutions, construction organisations, individual practitioners, technology developers, technology service providers, industry associations, communities of practice, and technology advocates.	Macro Diffusion Responsibilities *matrix*

http://www.bimthinkspace.com/2015/01/the-eight-components-of-market-maturity.html). They were asked to use the description provided to rate the eight components in their respective countries using the same aforementioned five-level index.

Two sets of ratings are generated from this model – by Country and by Maturity Component. The ratings *by country* are shown in Fig. 3 and reveal that the United Kingdom displays the highest cumulative maturity; followed by China, South Korea, Finland, the Netherland, Spain, and the United States. This highest cumulative rating of 17.7 pts is still relatively low when compared to the highest possible score of 32 points (4 points per component).

The index levels (0, 1, 2, 4 and 4) were converted into percentages (0%, 25%, 50%, 75%, 100%) and the rating by *component* are shown colour coded in Table 8, which offers a number of findings:

- None of the countries achieved the highest rating across all eight components. The UK has achieved highest maturity in the largest number of components (five out eight) compared to the other countries;
- All countries have gaps (white cells) in their macro BIM maturity.

Table 3
Selected 21 countries and number of experts.

Country	Participants	Country	Participants
Australia	4	Netherlands	4
Canada	4	Portugal	10
China	3	Qatar	6
Finland	5	Russia	2
Hong Kong	3	Spain	7
Malaysia	4	Switzerland	2
New Zealand	3	United Arab Emirates	3
Brazil	4	United Kingdom	16
Ireland	3	United States	5
Italy	5	South Korea	4
Mexico	3		

Table 4
Number of respondents for each model.

Model→	A	B	C	D	E
Respondents→	99	86	86	86	86

Table 5
Clarity of the five macro-BIM adoption models.

	A	B	C	D	E
High	20%	27%	48%	32%	39%
Medium-high	61%	45%	41%	43%	49%
Medium	15%	27%	9%	22%	12%
Medium-low	4%	1%	2%	3%	0%
Low	0%	0%	0%	0%	0%

Table 6
Accuracy of the five macro-BIM adoption models.

	A	B	C	D	E
High	11%	12%	32%	25%	26%
Medium-high	37%	53%	43%	37%	51%
Medium	38%	32%	19%	32%	20%
Medium-low	13%	2%	5%	5%	1%
Low	0%	1%	1%	1%	2%

Table 7
Usefulness of the five macro-BIM adoption models.

	A	B	C	D	E
High	20%	34%	38%	33%	42%
Medium-high	48%	46%	33%	32%	32%
Medium	26%	18%	20%	28%	24%
Medium-low	9%	1%	7%	5%	0%
Low	0%	1%	2%	2%	2%

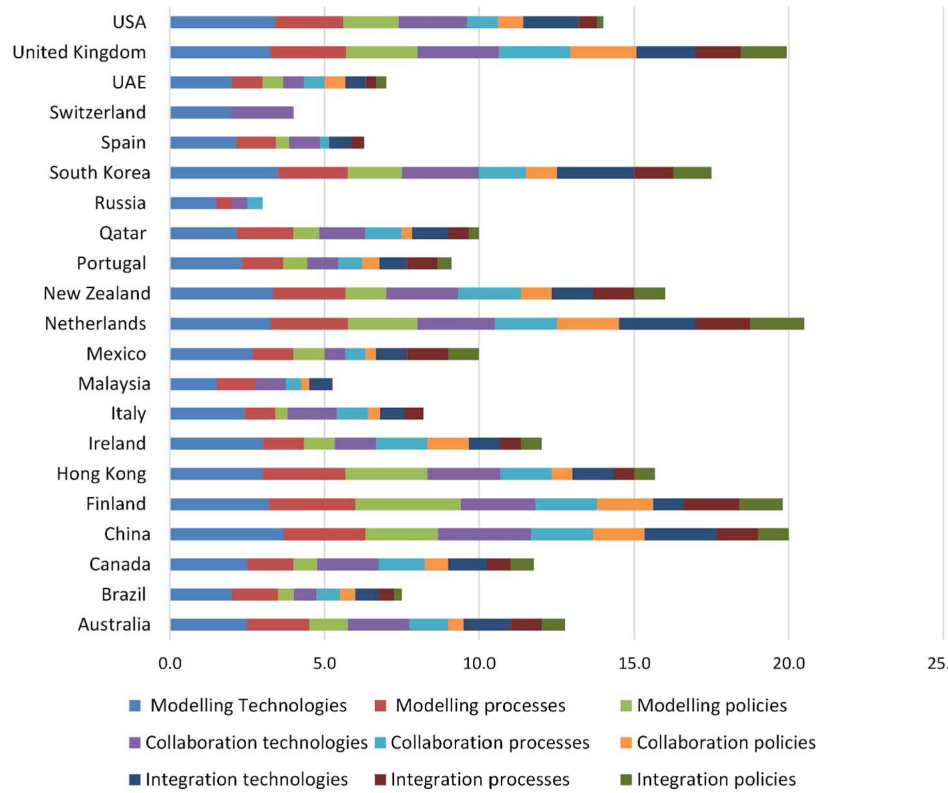

Fig. 1. The nine Diffusion Areas across the 21 countries.

For example, Canada has gaps in four macro maturity components; Switzerland has gaps in five macro maturity components (white cells); Russia has gaps in three macro maturity components; etc., and

- Most ratings of macro maturity components across the 21 surveyed countries (156 ratings out of 168 ratings – 8 ratings by country) are equal or below 50% which indicates a generalised Medium-Low maturity worldwide across many components.

Comments received from participants on this model highlighted the need to account for differences in maturity between the State and Federal Levels.

The confidence level obtained is adequate as evidenced from the standard deviations of the assessed model's elements across the 21 countries: 146 (87%) elements out of the 168 assessed elements (i.e. eight macro components in 21 countries) have their standard deviations within a unit interval on the applied Likert scale. These results are adequate for this study at its discovery stage and will improve as more data is collected in the future. The highest standard deviation (i.e. 1.5) is recorded once in Mexico for 'champions and drivers'.

Model C: comparing diffusion dynamics across countries.

Model C explains how diffusion occurs within a population of adopters. It identifies three diffusion dynamics (i.e., Top-down, Bottom-up and Middle-out) which embody a combination of *directional mechanics* (i.e., Downward, Upward and Horizontal) and *isomorphic pressures* (i.e., Coercive, Mimetic and Normative). These dynamics allow innovation to contagiously pass from 'transmitters' to 'adopters' [7,5,49].

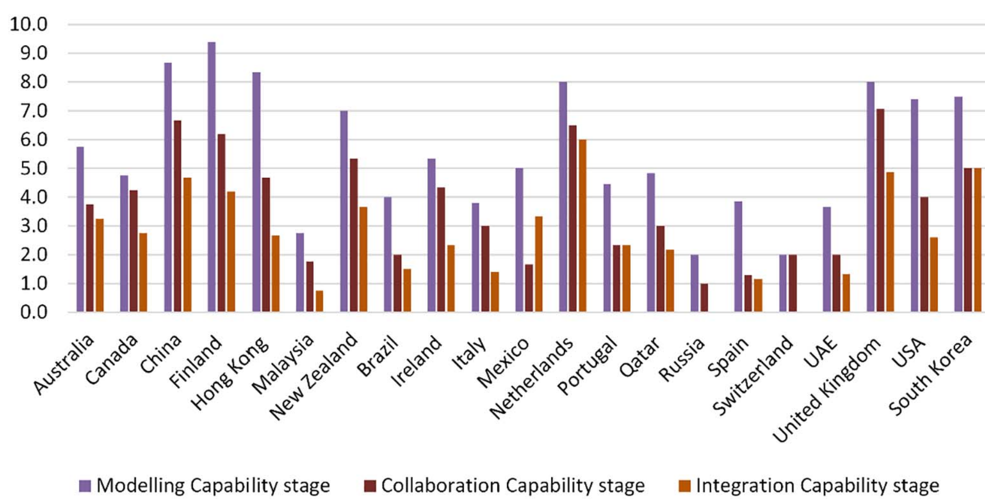

Fig. 2. Capabilities stages across the 21 countries.

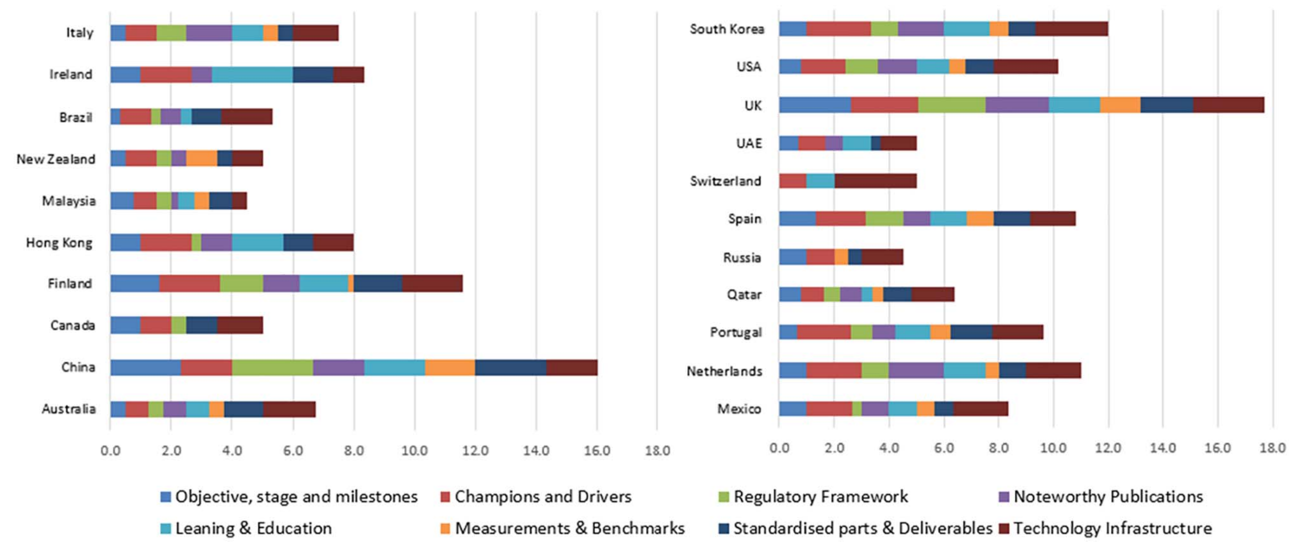

Fig. 3. Comparative rating of the macro-maturity components across the 21 countries.

Table 8
Comparison of the ratings (%) of each macro component across the 21 countries.

	Objectives, Stages & Milestones	Champions & Drivers	Regulatory Framework	Noteworthy Publications	Learning & Education	Measurements & Benchmark	Standardised parts & Deliverables	Technology Infrastructure
Australia	13	20	20	20	20	13	33	45
China	58	43	43	43	50	43	58	43
Canada	25	25	0	0	0	0	25	38
Finland	40	50	30	30	40	5	40	50
Hong Kong	25	43	25	25	43	0	25	33
Malaysia	20	20	8	8	13	13	20	13
New Zealand	13	25	13	13	0	25	13	25
Brazil	8	25	18	18	8	0	25	43
Ireland	25	43	18	18	68	0	33	25
Italy	13	25	38	38	25	13	13	38
Mexico	25	43	25	25	25	18	18	50
Netherlands	25	50	50	50	38	13	25	50
Portugal	15	50	23	23	33	20	38	48
Qatar	20	20	20	20	10	10	25	40
Russia	25	25	0	0	0	13	13	38
Spain	33	45	25	25	33	25	33	43
Switzerland	0	25	0	0	25	0	0	75
UAE	18	25	18	18	25	0	8	33
UK	65	63	58	58	45	38	48	65
USA	20	40	35	35	30	15	25	60
South Korea	25	58	43	43	43	18	25	68

Survey participants were asked to identify the diffusion dynamic driving BIM innovation within their respective countries, at the time of the survey. Their responses are summarised in Table 9 indicating the prevalence of the Middle-out dynamic (16 countries or 76% of the sample – Table 9). As discussed in Paper A, the expression of a Middle-out dynamic occurs when large and influential organisations (e.g. large construction companies or large public and private procurers) first adopt BIM internally and then push for a similar adoption *downwards* into their supply chain; *upwards* into regulatory bodies; and – due to mimetic pressures - *horizontally* into similarly large organisations.

While the prevalence of the Middle-out dynamic is clear by the data collected, it is important to note that diffusion dynamics may change over time. This is highlighted by the survey participants from Brazil who clarified that - in their market - BIM was first adopted by small architectural firms and gradually diffused upwards into large engineering and contracting organisations, which then caused a formal adoption

Table 9
Current diffusion dynamics in 21 countries.

	Top down	Middle-out	Bottom-up		Top down	Middle-out	Bottom-up
Australia		•		New Zealand			•
Brazil		•		Portugal		•	
Canada		•		Qatar		•	
China		•		Russia		•	
Finland		•		South Korea		•	
Hong Kong	•			Spain			•
Ireland		•		Switzerland		•	
Italy		•		UAE	•		
Malaysia		•		UK	•		
Mexico		•		USA		•	
Netherlands		•					

by some of the states and the federal governments. Following that Bottom-up diffusion dynamic, the federal government started to encourage a BIM adoption by smaller market players thus expressing a Top-down dynamic. Spain was also witnessing a similar diffusion dynamic at the time of the survey. It is also possible that different diffusion dynamics may be expressed concurrently as explained by a participant from the United States: a Middle-out dynamic was clear when the General Services Administration (GSA), US Army Corps of Engineers, Veterans Affairs and many others were encouraging their supply chains to adopt their BIM guides and protocols [16]. At the same time, a Bottom-up dynamic was being expressed by a large number of small design consultancy firms which adopted BIM tools and workflows internally and then encouraged their adoption upwards by large contractual firms.

According to the participants, a Top-down diffusion dynamic is currently expressed in three countries - Hong Kong, the United Arab Emirates and the United Kingdom - due to their currently enforced BIM adoption mandates.

Model D: comparing policy actions across countries.

Model D identifies the actions policy makers take (or can take) to facilitate market-wide adoption of an innovative system/process. The model establishes nine actions through mapping three implementation *activities* (communicate, engage and monitor) against three implementation *approaches* (passive, active and assertive). Using the model, research participants were asked to select three actions that best represent the approach taken by their respective policy makers. The selections helped identify a number of patterns (Table 10):

- Pattern 1 – fully passive: A1 (Make Aware), B1 (Encourage) and C1 (Observe). This pattern applied in 14 countries: Australia, Brazil, Canada, Ireland, Italy, Malaysia, Mexico, New Zealand, Portugal, Qatar, Russia, Spain, Switzerland and the United Arab Emirates.
- Pattern 2 – mostly passive: A2 (Educate), B1 (Encourage) and C1 (Observe). This pattern was identified in five countries: China, Finland, Hong Kong, South Korea and the USA.
- Pattern 3 – mostly active: combining either A2 (Educate), B2 (Incentivise) and C1 (Observe) or A2 (Educate), B3 (Enforce) and C2 (Track). These combined two patterns were found in two countries, the Netherlands - combining active and passive approaches – and the UK – combining active and assertive approaches.

According to the data collected, the model identifies a number of common policy-action patterns. The coexistence of different patterns highlight how policy actions differ from one country to another and that policy makers may influence the adoption of innovative solutions through "a judicious mix of information provision and subsidies" ([10],

Table 10
Policy action types across the 21 countries.

	Communicate			Engage			Monitor		
	A1 Make aware	A2 Educate	A3 Prescribe	B1 Encourage	B2 Incentivise	B3 Enforce	C1 Observe	C2 Track	C3 Control
Australia	•			•			•		
Brazil	•			•			•		
Canada	•			•			•		
China		•		•			•		
Finland		•		•			•		
Hong Kong		•		•			•		
Ireland	•			•			•		
Italy	•			•			•		
Malaysia	•			•			•		
Mexico	•			•			•		
Netherlands		•			•		•		
New Zealand	•			•			•		
Portugal	•			•			•		
Qatar	•			•			•		
Russia	•			•			•		
South Korea		•		•			•		
Spain	•			•			•		
Switzerland	•			•			•		
UAE	•			•			•		
UK		•				•		•	
USA		•		•			•		
Action type frequency	14	7	0	20	1	1	20	1	0

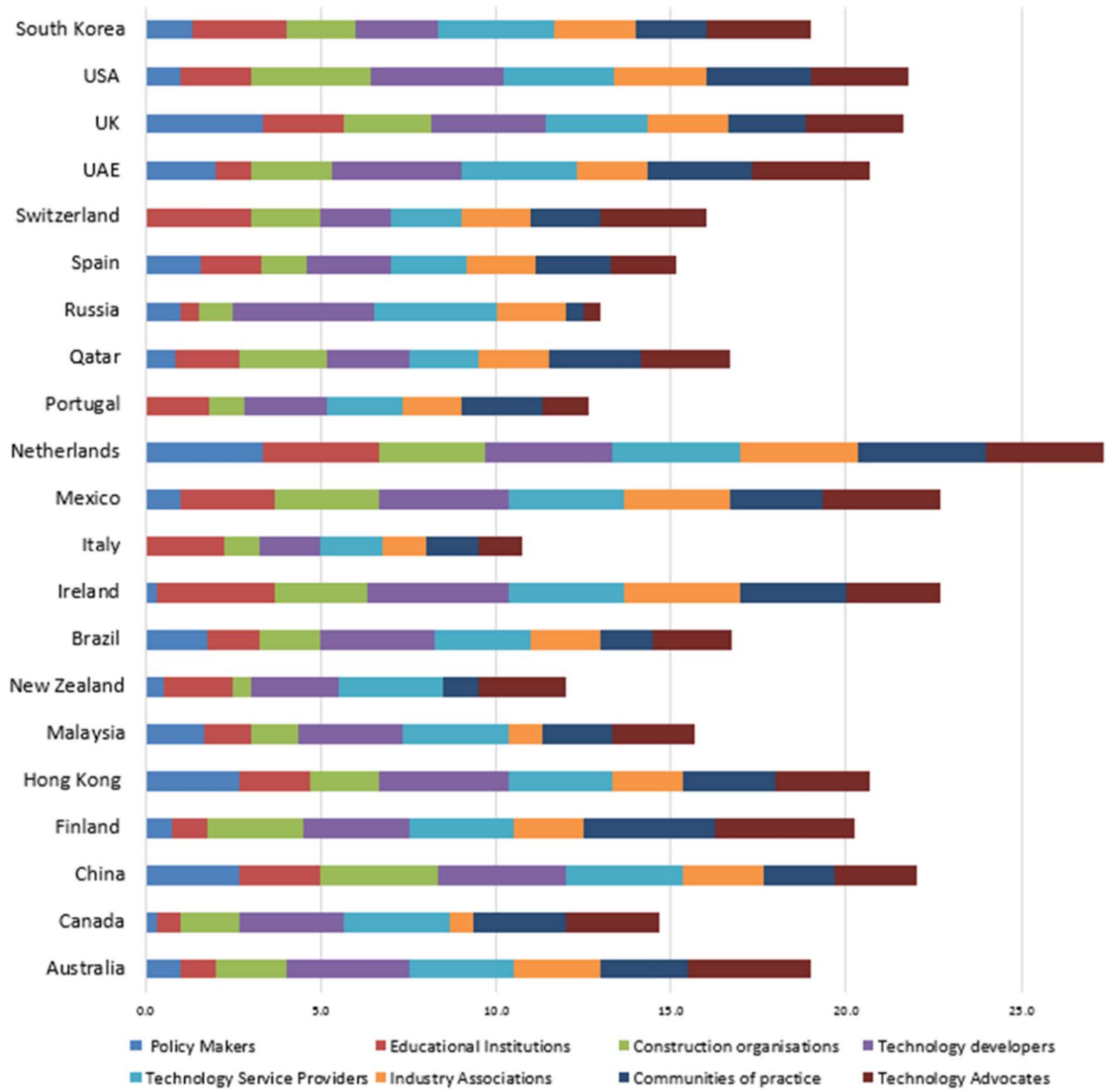

Fig. 4. Comparing the role of the eight stakeholders within each country.

p. 621).

When the results of this model are seen in conjunction with those of model C, a clearer picture of the diffusion dynamics can be established. A top down dynamic (e.g. a mandate) identified in model C should not be confused with an assertive approach in model D. For example, a top down dynamic in Model C (e.g., mandate) could still result in a fully passive approach depending on the actions undertaken by policy makers. This was witnessed in the case Hong Kong and the UAE. In both countries, while model C identified a top-down diffusion dynamic, model D identified a fully passive approach (A1: Make Aware, B1: Encourage and C1: Observe). From a theoretical perspective, it is important to understand the effect of or the relationships between different policy activities and approaches and resultant BIM diffusion dynamics. This is a research gap that warrants attention.

Model E: comparing player group responsibilities across countries.

Model E enables the assessment and comparison of the roles played by different stakeholder groups in facilitating diffusion within and across markets. The model identifies nine BIM player types (stakeholders) distributed across three BIM fields - technology, process and policy [39,40]: authorities, construction organisations, software developers, educational institutions, individuals, value-adding resellers, industry associations, communities of practice, and technology advocates. Using a five-level scale, research participants were asked to rate the involvement of the eight stakeholder in facilitating or encouraging BIM diffusion in their respective countries. The results compare the diffusion activities of a number of player groups within the same market (Fig. 4); and compare the BIM diffusion activities of players pertaining to the same group across different markets (Table 11).

Fig. 4 shows that the involvement of the eight stakeholders in facilitating and encouraging BIM diffusion varies across countries. The chart highlights how in the Netherlands, South Korea, Hong Kong, China and the United Kingdom – stakeholders play a balanced role. It also indicates that the Netherlands is the only country where all eight stakeholders achieved an above medium score.

Table 10 compares role of each player type across the 21 countries. It is evident from the results that, with the exception of 'Technology Developers' who play a significant role in most countries, there is not a player type that play a predominant role across all countries. Also the results from this model warrant further investigation by researchers. In particular, there is a need to understand the relationships between the role played by the player types (Model E), under different policy action types (Model D) and the resultant diffusion dynamics (Model C).

The standard deviations from the application of this model demonstrated elevated confidence levels: 134 (80%) out of the 168 assessed

Table 11
Comparing the rated contribution (%) of each stakeholder to BIM diffusion across the 21 countries.

	Policy Makers	Educational Institutions	Construction Organisations	Technology Developers	Technology Service Providers	Industry Associations	Communities of Practice	Technology Advocates
Australia	25	25	50	88	75	63	63	88
Canada	8	18	43	75	75	18	68	68
China	68	58	83	93	83	58	50	58
Finland	20	25	70	75	75	50	95	100
Hong Kong	68	50	50	93	75	50	68	68
Malaysia	43	33	33	75	75	25	50	58
New Zealand	13	50	13	63	75	0	25	63
Brazil	45	38	45	83	70	50	38	58
Ireland	8	83	68	100	83	83	75	68
Italy	0	58	25	45	45	33	38	33
Mexico	25	68	75	93	83	75	68	83
Netherlands	83	83	75	93	93	83	93	83
Portugal	0	45	25	58	55	43	58	33
Qatar	20	45	63	58	50	50	68	63
Russia	25	13	25	100	88	50	13	13
Spain	40	43	33	60	53	50	53	48
Switzerland	0	75	50	50	50	50	50	75
UAE	50	25	58	93	83	50	75	83
UK	85	58	63	83	73	58	55	70
USA	25	50	85	95	80	65	75	70
South Korea	33	68	50	58	83	58	50	75

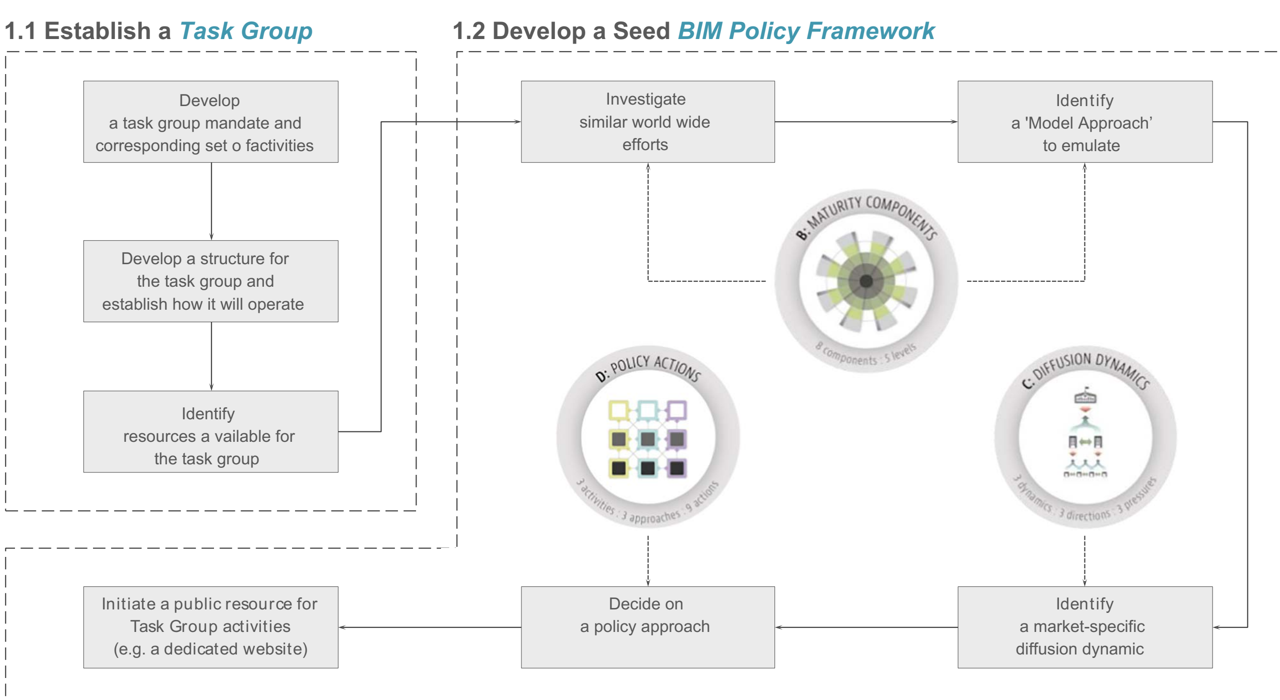

Fig. 5. The Initiation Phase of the Policy Development Plan.

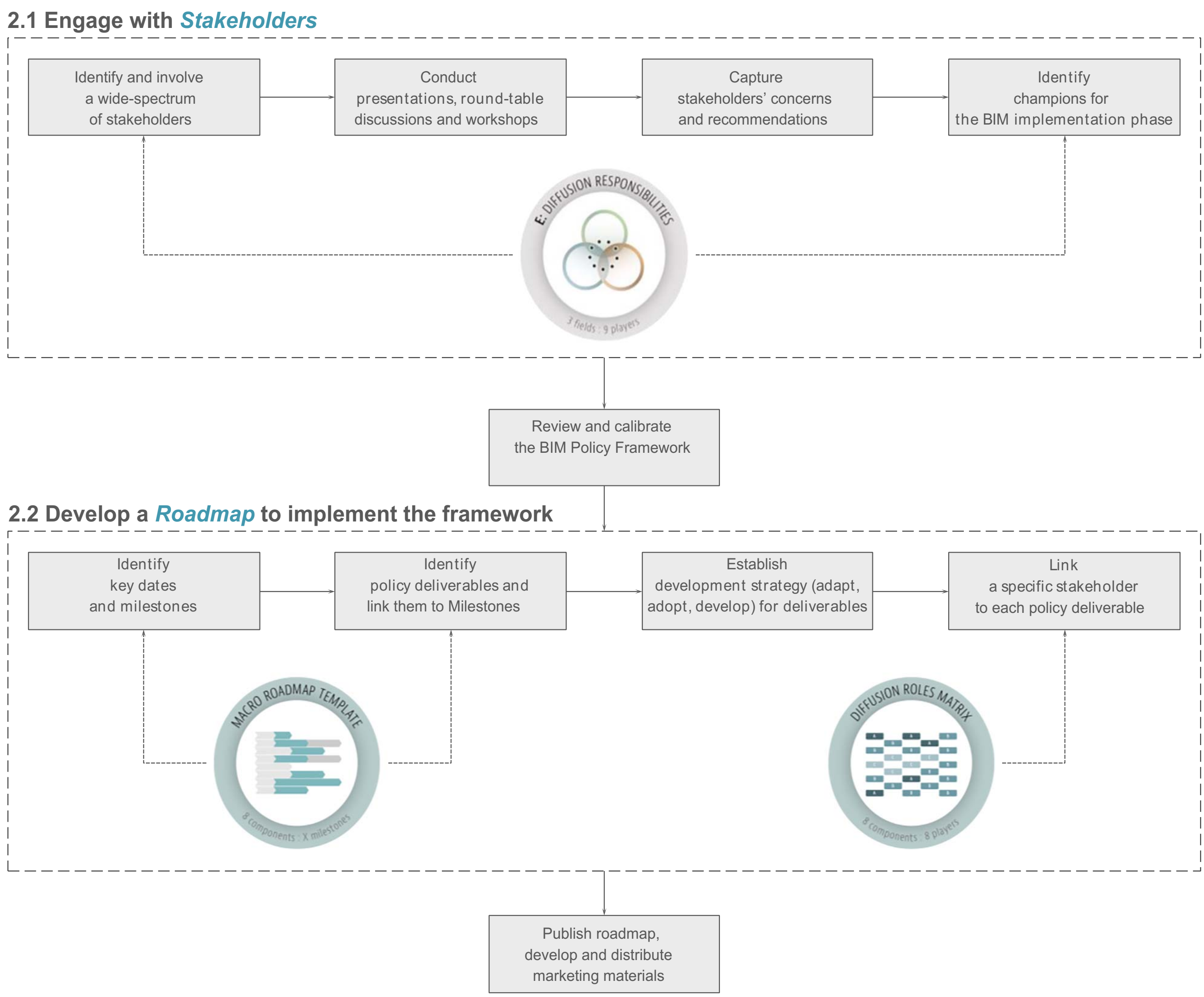

Fig. 6. The Consultation Phase of the Policy Development Plan.

elements (i.e. role of eight player groups in 21 countries) were within a unit interval on the applied Likert scale. These results are adequate for this study at its *discovery* stage and will improve as more data is collected in the future. The highest standard deviation (i.e. 1.7) is recorded four times: one occurrence in Hong Kong for 'educational institutions'; two occurrences in Italy for 'technology developers' and 'technology service providers'; and one occurrence in Korea for 'technology advocate'.

4.3. Discussion of results

The application of model A (Diffusion Areas model) showed that the nine areas of diffusion vary within the same country and across countries. However, a general trend appeared with the highest rates scored in modelling diffusion areas (low capability stage) followed by lower rates in collaboration (medium capability stage) and integration (high capability stage) diffusion areas. This finding provides the empirical evidence for the gradual progression across the revolutionary BIM capability stages developed by Succar [39,40], and subsequently expanded in Succar [40,41] and Succar and Kassem [44]. This model can be used in a national BIM policy to establish diffusion levels of staged capability milestones within a market (e.g. by 2016: 50% diffusion rate of modelling capabilities, 30% diffusion rate of collaboration capabilities, 20% diffusion rate of integration capabilities). This is a more detailed and measurable approach than the broadly-defined whole-market milestones introduced in a number of countries (e.g., Level 2 BIM in the UK).

The application of model C (Diffusion Dynamics model) showed that BIM diffusion unfolds according to different dynamics in the 21 selected countries, with the 'middle-out' dynamic being the prevalent dynamic. This is a significant finding as the middle out dynamic is infrequently acknowledged and identified in innovation adoption studies. The different diffusion dynamics are interdependent and should not be considered in isolation. An innovation which is being diffused at among small organisations (bottom tier) can move all the way up the chain to government bodies (top tier). From the additional comments by respondent, this situation was witnessed in Spain where small architectural and engineering organisations adopted BIM and then, the diffusion unfolded upwards to large engineering and contractor organisations, who are now conveying it upwards to large regional and central government bodies. This difference in diffusion dynamic across countries is associated with a variety of market-driven and social variables [5,7,47]. Some recent investigation based on small number of case studies, suggest economic insights (i.e. transaction costs), value (i.e. trust and reputation) and social learning have impact on the adoption of BIM collaborative working in construction industry [36]. BIM-specific investigations of the relationship between market-driven and social variables and BIM diffusion is still an under-investigated area and deserve more attention from the research community.

Model D (Policy Actions model) showed that the types of policy actions, undertaken by policy makers for BIM diffusion, vary between countries. In the majority of counties (14 out of 21), the approach to all

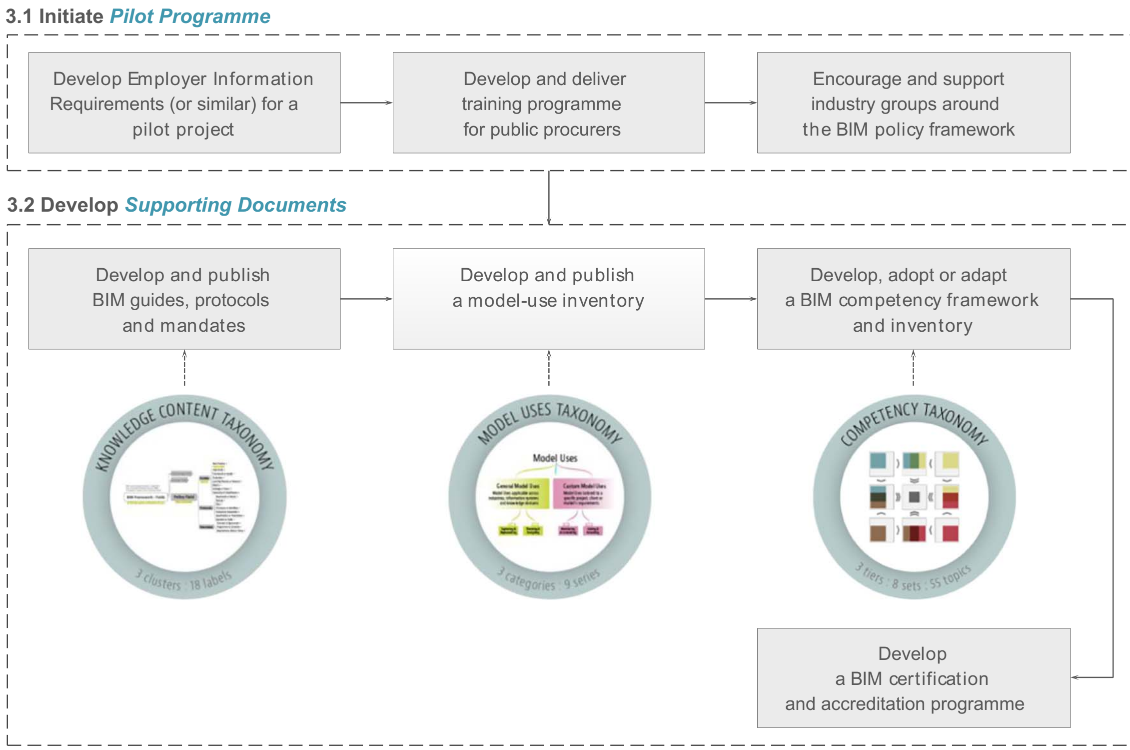

Fig. 7. The Execution Phase of the Policy Development Plan.

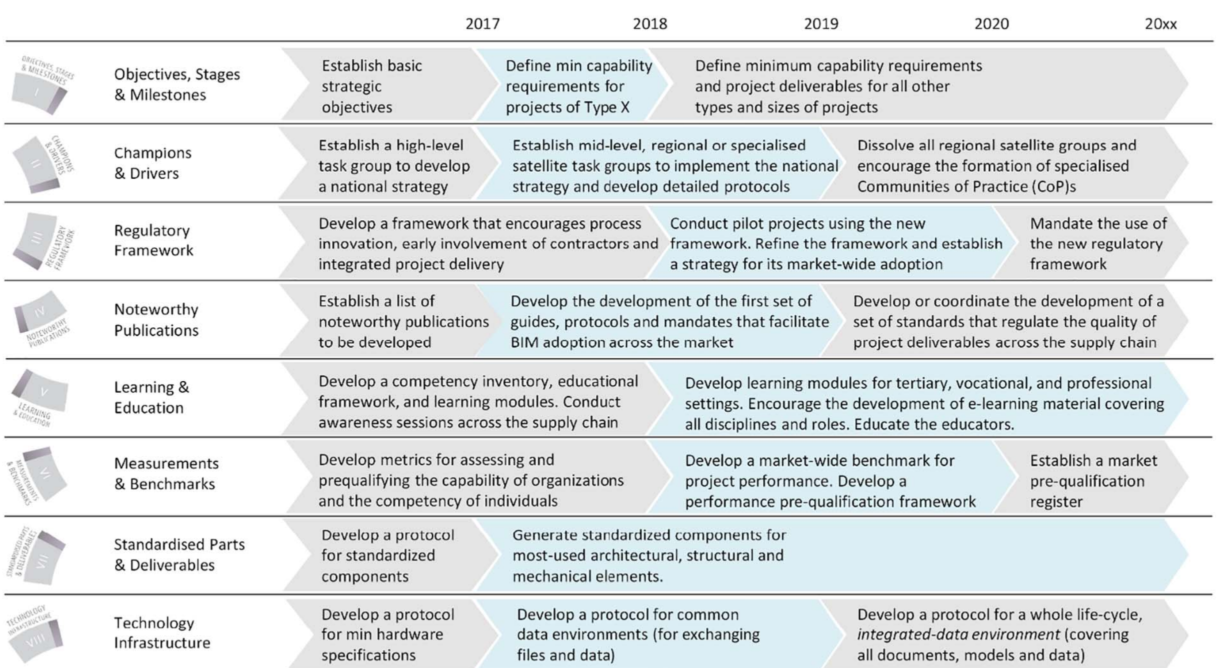

Fig. 8. Template for developing a national BIM roadmap.

three implementation activities (i.e., communicate, engage and monitor) is considered passive. In other countries, policy makers have combined both the passive and active approach. Only in the UK, the approach consisted of only active and assertive actions. These mixed approaches adopted by policy makers conform to finding in diffusion innovation studies where the adoption of innovative solution occur through "a judicious mix of information provision and subsidies" ([10], p. 621). The impact of the different policy actions - and their related tasks - under the three different approaches (i.e. passive, active, and assertive) on BIM diffusion is an uncharted area that requires attention from research community. It is also valuable to conduct such an investigation in markets with varying diffusion dynamics as the same policy actions could have varying effects under different dynamics.

The application of model E (Macro Diffusion Responsibilities model) demonstrated that the Macro BIM diffusion is a whole-market dynamic that requires efforts from all stakeholders although their contribution varies across countries. This finding is also supported with evidence in prior studies on innovation diffusion. The role of any stakeholder and actor in innovation diffusion should not be neglected [20] as the spread of innovations occur in networks of actors and stakeholders [22]. While

Macro Maturity Components — Diffusion-Role Matrix v1.0 *sample shown at GLevel 1* (Succar, 2015)

Macro Player Groups	Objectives , Stages and…	Champions & Drivers	Regulatory Framework	Noteworthy Publications	Learning & Education	Measurements & Benchmarks	Standardised Parts and…	Technology Infrastructure
Policy Makers	A	A	A	B	B	A	B	C
Educational Institutions	B	B	A	A	A	B	C	C
Construction Organizations	B	A	B	B	B	A	A	B
Individual Practitioners	C	C	C	C	A	C	C	C
Technology Developers	C	C	C	C	B	C	B	A
Technology Service Providers	C	C	C	B	A	C	B	A
Industry Associations	B	B	A	A	B	A	C	C
Communities of Practice	C	B	C	B	B	C	A	C
Technology Advocates	A	A	B	A	B	B	A	B

[A] Leading, [B] Supporting, & [C] Participating roles

Fig. 9. A template for assessment and planning of diffusion roles.

the need for a joint responsibility for BIM diffusion is an opportunity to involve the different player groups, it presents some key challenges to the development and implementation of national BIM policies especially when the policy development effort is not coordinated centrally. Such challenges include: the risk of implementation gap in the BIM diffusion process; the risk of duplication of efforts and the generation of overlapping deliverables, and the risk of limited engagement by some stakeholders. The next section will demonstrate how the identified challenges can be addressed while using the Macro-Adoption models and their corresponding tools for policy development purpose (e.g. development of national BIM roadmap).

5. Part II: using the models to develop BIM policy plans and templates

The application of the models and their tools to assess and benchmark the 21 selected countries showed their ability to successfully assess and benchmark national BIM policies. Following their validation with 99 experts from 21 countries, the model can now be exploited to promote learning about BIM policy making across countries. The assessment and benchmark provides the foundation to learn about a specific and individual macro adoption topic of a country and the result can be used in the development of the BIM policy of another country as demonstrated in a brief example in the discussion section. However, to benefit from macro adoption models in the development of national BIM policies, further plans/workflows, tools and templates for macro BIM policy development are required. This section proposes a Policy Development Plan, a tool for planning macro diffusion responsibilities and a template of a BIM roadmap.

The proposed Policy Development Plan has three key phases which are the Initiation Phase, the Consultation Phase and the Execution Phase.

5.1. Initiation Phase

The Initiation Phase (Fig. 5) aims to establish both the Task Group and the seed BIM Framework that will guide the national BIM policy. The Task Group will be the key driver who will coordinate the delivery of the national BIM policy. In this phase, models B, C and D are respectively used to, assess worldwide efforts, identify the market-specific diffusion dynamic, and establish a policy approach. If the approach of another country is emulated in the development of the seed BIM framework, it is important to ensure legitimacy to the country's context and ecosystem. Policy effectiveness, receptivity, and response are tightly coupled with the degree to which policies are crafted for the contexts in which they are being applied [33,34,46,49].

5.2. Consultation Phase

The Consultation Phase (Fig. 6) aims to communicate the vision, the Task Group Mandate and the seed BIM Framework to the industry and ensure engagement. At this stage, the seed BIM framework is refined and converted into a roadmap and the responsibilities for each of the roadmap items are assigned to selected stakeholders. A template for developing the roadmap is provided in Fig. 8. This roadmap is built by assigning a timeline – including key dates and milestones - against the eight macro-components of Model B. Then, each policy deliverable required for the roadmap is linked to a milestone and assigned to a selected stakeholder. A Diffusion Role matrix (Fig. 9) can be used to assign responsibilities to selected stakeholders for each of the planned deliverables. This sample Diffusion-Role Matrix clarifies who is doing what (diffusion assessment – as performed in the presented survey) or who should be doing what (diffusion planning). Three different roles are envisaged for different stakeholders:

- [A] Leading Role played by those responsible for initiating, developing and maintaining a structured diffusion effort (e.g. developing a strategy, a standard or a data-validation tool);
- [B] Supporting Role played by those assisting the Leading Role to communicate and engage with other players, and in delivering diffusion components; and
- [C] Participating Role played by early adopters of innovative systems/processes.

These Player Roles are neither exclusive nor permanent. A macro diffusion component (e.g. Regulatory Framework) can be led by more than one player, and the Leading Role may pass from one player to another over time. Also, a Leading Role may be played by any player type. For example, developing the overall BIM Objectives, Strategy and Milestones (Component I in model B) may be led by a Policy Maker (e.g. BCA in Singapore) and/or by a Technology Advocate (e.g. buildingSMART in Spain). In essence, the participation and distribution of Player Roles among Player Groups depends on market-specific organisational culture, macro diffusion dynamics, and policy implementation approaches.

This Diffusion Role matrix contributes to the establishment of a coordinated diffusion effort in which duplication is minimised; potential diffusion gaps are avoided, and stakeholders' participation is encouraged.

At the Consultation Phase, an initial decision whether to adopt an existing (e.g. an international standard), adapt (tailor to market requirements) or develop a new policy deliverable is made for each planned policy deliverable. This phase concludes with the publication of the roadmap which is ready for the Execution Phase.

5.3. Execution Phase

The Execution Phase (Fig. 7) initiates pilot programmes to test the policy deliverables. For example, a request for tender for a project that requires fulfilling a specific compliance milestone (e.g. UK Level 2), Employer Information Requirements and/or performance milestone (e.g. Capability Stage 2, Maturity Level c) is issued to test the supporting standards and protocols. Training programmes for public procurers are developed and delivered at this stage. An extensive campaign of encouraging and supporting industry groups around the BIM policy framework is executed. Two key industry groups that must be engaged at this stage are the User Groups (Communities of Interest) and the Education Task Group. The User Group engages in sharing knowledge, testing standards and developing best practice protocols. The Education Task Group engages in developing competency lists, learning frameworks and modules. All activities and deliverables (e.g., BIM-centric Procurement Guide, model contract clauses or templates, competency and model use inventories, BIM certification and accreditation programmes, etc.) included in the roadmap developed at the Consultation Phase are delivered – developed and tested – at this phase.

In policy development guides, the review and evaluation is often positioned as a distinct phase at the end of the policy development cycle. In the proposed Policy Development Plan, the review and evaluation activities are embedded across the whole policy development lifecycle from initiation, through consultation, to execution. This is important as new policies must have evaluation of their effectiveness built in from the start [8]. At the Initiation Phase, the adequacy of the established Task Group and the resources available to them are evaluated with the support of experts. At the Consultation Phase, both the seed BIM Framework and the Roadmap are extensively evaluated with industry groups in terms of their feasibility and impact. Finally, at the Execution Phase, all policy deliverables are assessed with the corresponding industry groups and feedback is collated to improve such deliverables.

6. Conclusion

Understanding and facilitating BIM adoption across markets is of increasing interest to policy makers researchers and other construction industry stakeholders. The three key challenges in this area are: the lack of models and tools that support policy makers in developing adoption policies, the lack of benchmarks to assess and comparing whole markets, and the dearth of guides for macro-BIM policy development. Paper A [43] addressed the first challenge by providing the five conceptual Macro-BIM adoption models that help policy makers to assess an existing policy effort or develop a new one. This paper (paper B) addressed the remaining two challenges by (i) validating the five models with the participation of 99 experts from 21 countries and (ii) applying the five models in assessing and comparing the national BIM policies across 21 countries.

As the data revealed, the five models enjoy high levels of 'clarity', 'accuracy' and 'usefulness'. More specifically, Model A (Diffusion Areas *model*) showed varying rates for its nine diffusion areas within the same country and across countries. It also demonstrated that, in most countries, diffusion occurs according to a staged approach where high diffusion rates were concentrated in modelling capabilities followed by collaboration and integration capabilities. This empirically demonstrated the concept of progression across the revolutionary stages (object-based modelling, model-based collaboration, and network-based integration) presented in Succar [39,40].

Model B (Macro Maturity Components *model*) showed that there is not any individual country that has higher maturity than the other countries in more than three topics of the eight macro adoption topics. It also identified specific gaps – or topics – in the national BIM policy of several countries that would have remained uncovered by survey approaches that have been used to date in academia and practice.

Model C (Macro Diffusion Dynamics *model*) identified varying diffusion dynamics across the 21 countries with the prevalence of the middle-out diffusion dynamic, identified in 14 countries.

Model D (Policy Actions *model*) identified varying policy actions across countries with a predominance of the passive policy approach. Model E (Macro Diffusion Responsibilities *model*) assessed and compared the distribution of diffusion responsibilities among player groups within the same country and across countries. In some countries, there are different player groups leading the diffusion effort. In other countries, there is a joint and balanced diffusion responsibility among the player groups.

The application of the models identified a number research gaps that require further attention from the research team and the research community in general. The gaps include the need to undertake (a) macro BIM studies to investigate the relationships between BIM diffusion and market-driven social variables; and (b) macro BIM studies that analyse the impact or effect of the different policy actions in markets with different diffusion dynamics.

While the models can promote the learning about BIM policy development among countries through their capability of structuring macro adoption topics and isolating the topic of interest, there still need to facilitate their use by policy makers. In particular, a policy development guide and a number of templates are needed. In the second part, an initial Policy Development Plan, a BIM roadmap template, and Diffusion Role Matrix were presented to fulfil this need. The Policy Development Plan has three interlinked phases that enable the development of structured national BIM initiatives. The Macro-BIM adoption models and their corresponding tools are used at different steps across the three phases of the Policy Development Plan. Together the Policy Development Plan and the accompanying templates will contribute towards the development of structured national BIM policies that have no diffusion gaps or overlap between their deliverables.

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